An aerial photograph showing a flooded landscape. A large body of water, likely a river or lake, dominates the foreground and middle ground. A long bridge spans across the water in the lower half of the image. In the background, a town or city is visible, with buildings and roads partially submerged in water. The overall scene suggests a significant flooding event, possibly related to the ENSO (El Niño/Southern Oscillation) phenomenon mentioned in the title.

Circulation variability and intense precipitation: A case study of ENSO and the American West

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with thanks to Lynn McMurdie (UW)

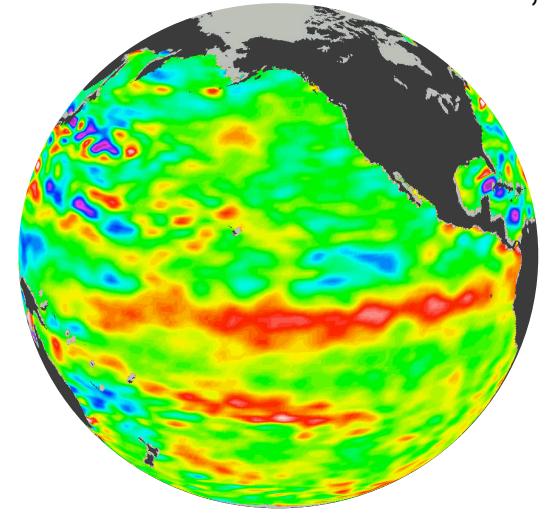
A climate science challenge

- How are changes in precipitation accomplished? Expectations from theory and modeling studies
 - Global mean based on energy balance constraints (thermodynamics) [Allen and Ingram, 2002; Trenberth, 2003]
 - Regional mean based on moisture fluxes (dynamics) [Held and Soden, 2006]
- GCMs struggle to successfully simulate the observed distribution of daily precipitation [Sun et al., 2006; Wilcox and Donner, 2007; Allan and Soden, 2007]
- Going beyond the mean ... How do dynamical changes in the hydrological cycle affect the statistical distribution of precipitation?

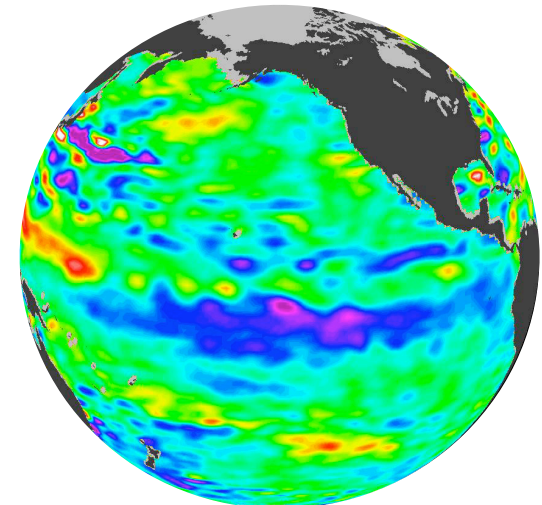
El Niño Southern Oscillation: A case study of variability

- A dominant pattern of interannual climate variability
 - Temperature, precipitation anomalies; shift of jet and storm tracks
- Straddles dry subtropics and wet midlatitudes
- Response of ENSO itself to a warmer climate is unclear [Lu, Chen, and Frierson, 2008; van Oldenborgh et al., 2005]
- ENSO as proxy for changes in midlatitude circulation patterns, not as an analog for future climate

Sea level height anomalies
El Niño, Oct. 2006

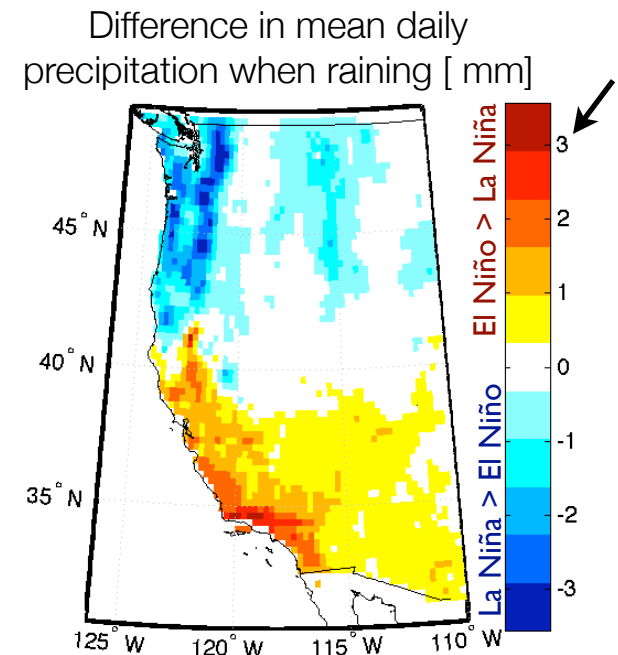


La Niña, Nov. 2007

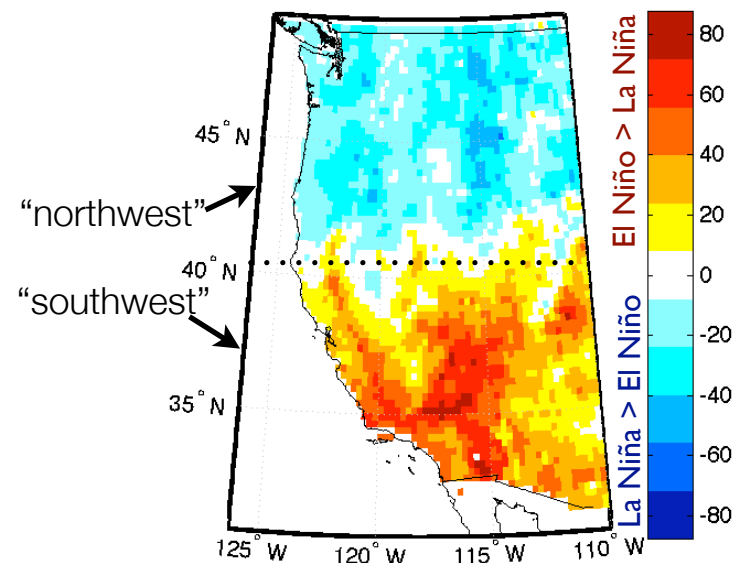


Statistical analysis of the mean and shape: A summary

- Confirms canonical picture in the mean
- Striking nodal line at 40°N
- Shape
 - Increases in tails during El Niño in the southwest and La Niña in the northwest
 - Changes in the shape independent of shifts in the mean - requires **redistribution**



Percent difference in mean daily precipitation when raining

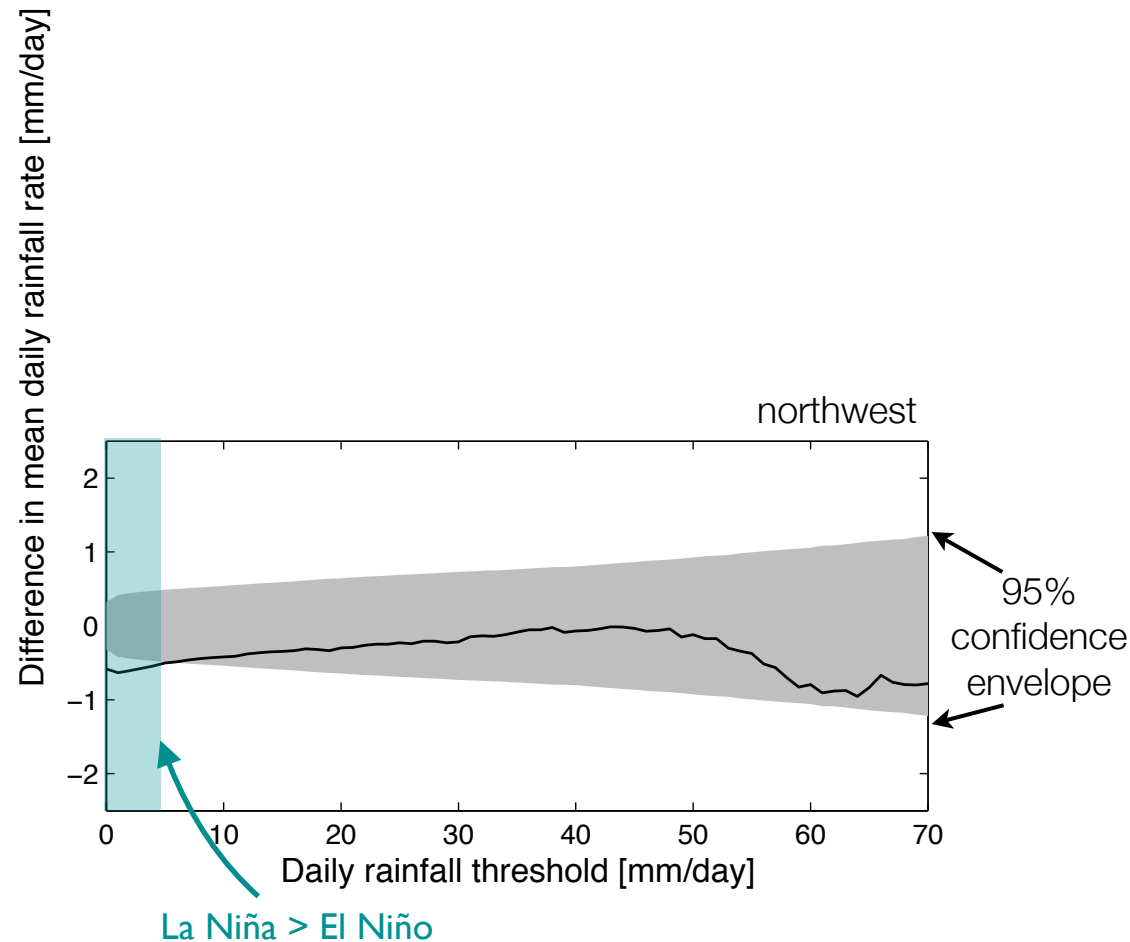


Extreme precipitation: Considering the tails

- Apply range of thresholds on cell-by-cell basis to search for local extremes
 - throw out all data at smaller values, i.e. 0 mm/day threshold = all data, 20 mm/day threshold = all precipitation ≥ 20 mm/day

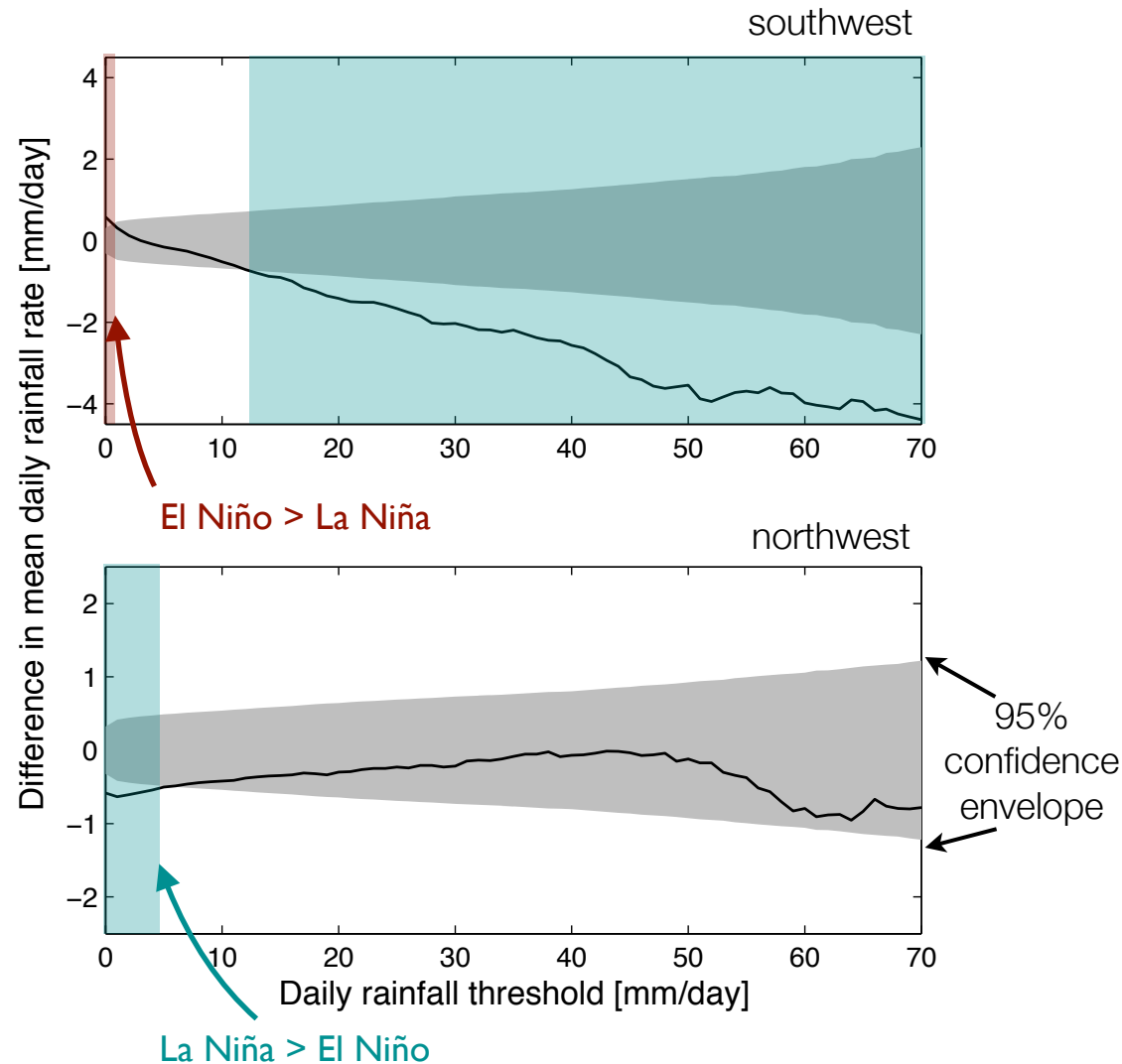
Difference in intensity as a function of threshold

- Gray envelope, 95% confidence
- No threshold case (0 mm/day)
- La Niña intensity is larger in the northwest, although start to lose significance for higher thresholds
- In stark contrast is the southwest case: As threshold is raised, La Niña exceeds El Niño



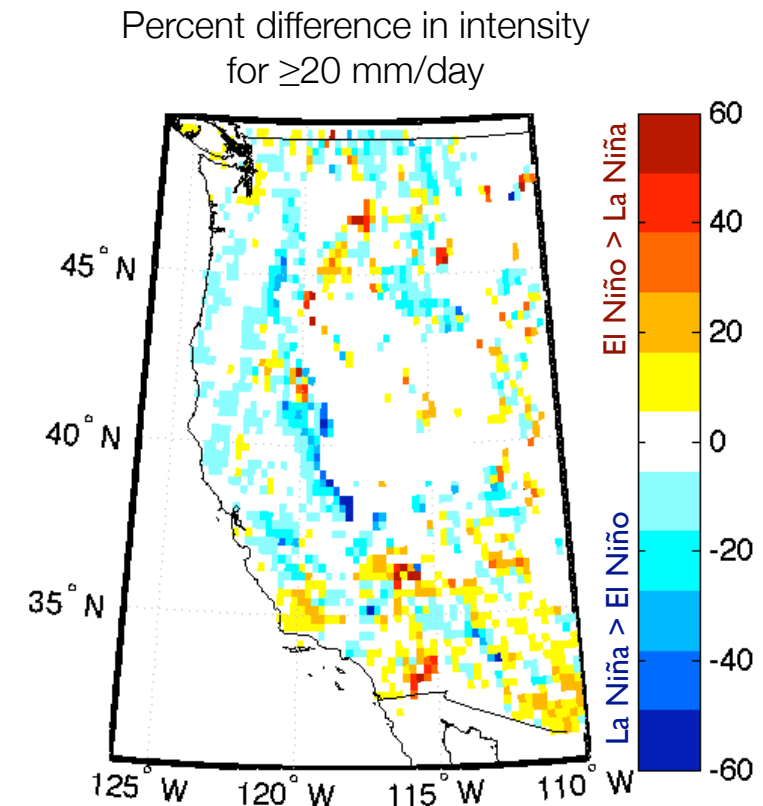
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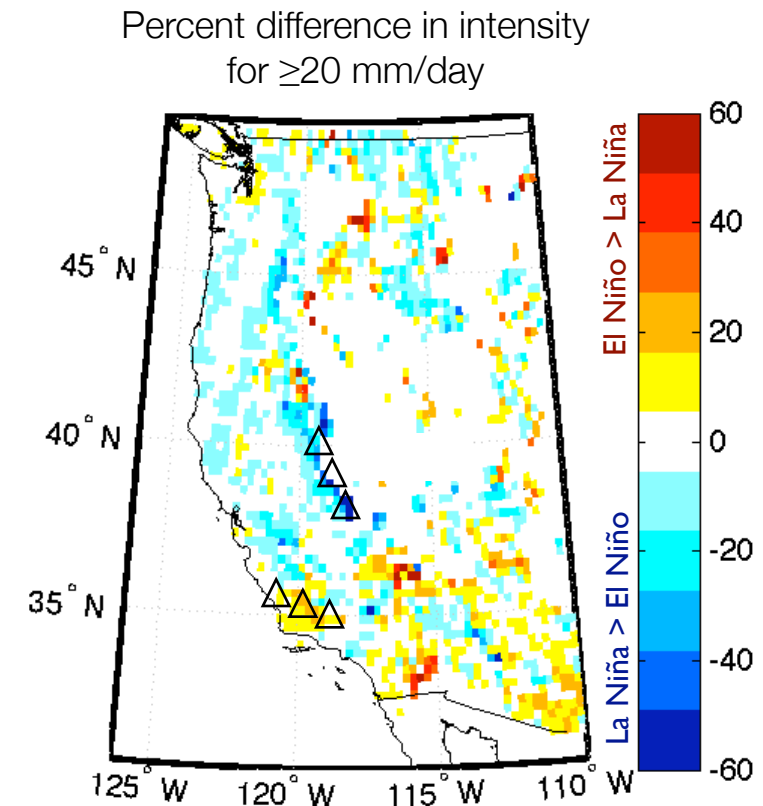
What is the spatial pattern?

- Diffuse but widespread across the West
 - High spatial variability
 - High variability in time series
- Hint of an orographic control
- An intensity, rather than frequency, signal (redistribution required)
- Impacts



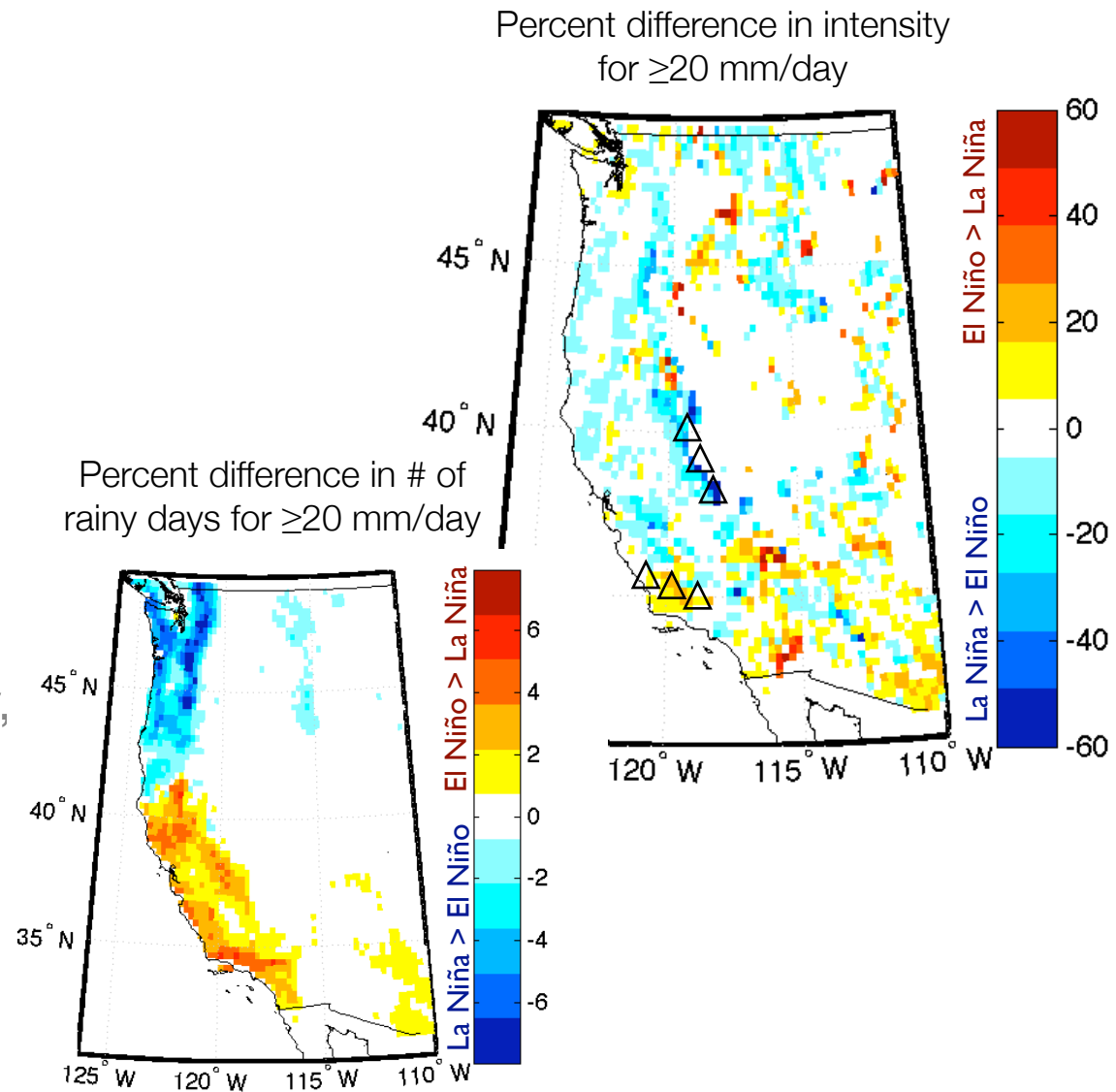
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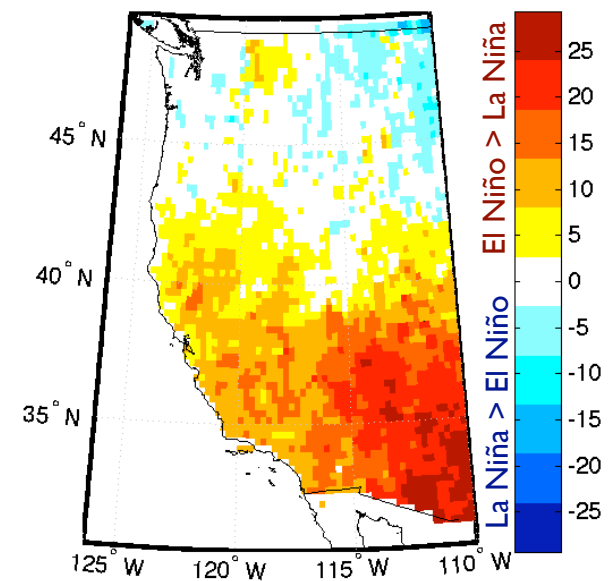
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- Impacts



How robust is the 40°N climate zone “boundary”?

- Neither the frequency of drizzle nor the intensity of heavy precipitation follow the same climate zones as the mean
- Frontal processes
- Changes in drizzle/extremes have a different spatial expression than changes in the mean
- Synoptic patterns associated with the intense precipitation result ...

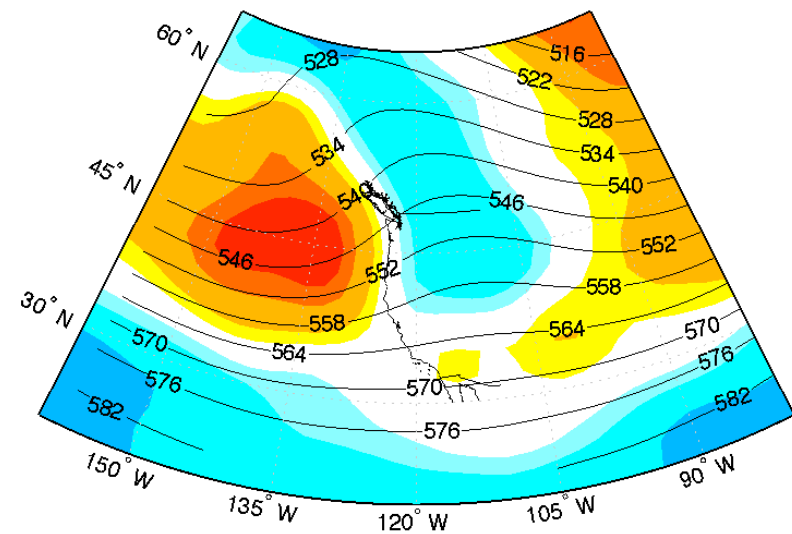
Percent difference in # of rainy days



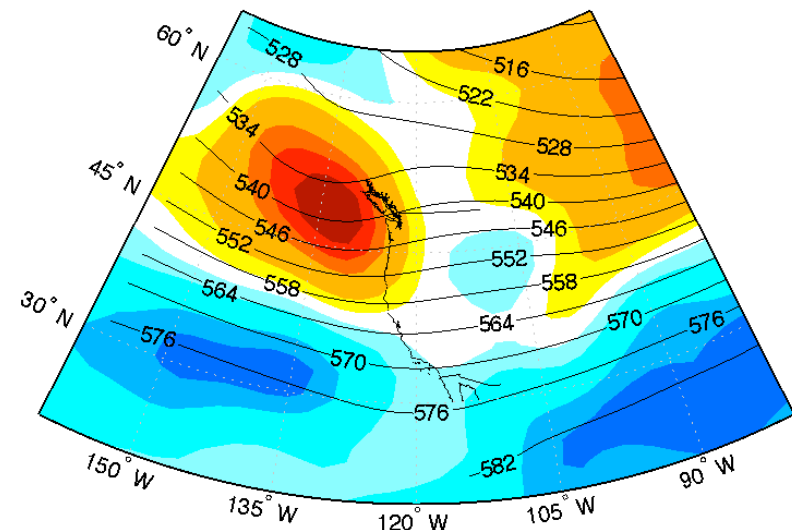
Geopotential height and relative vorticity

- Composite all La Niña and El Niño days with precipitation exceeding 20 mm/day south of 40°N
- Enhanced La Niña vorticity (deeper trough)
- Secondary zone of enhanced El Niño vorticity

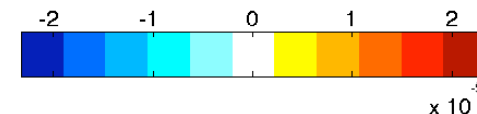
El Niño (526, 43%)



La Niña (384, 34%)

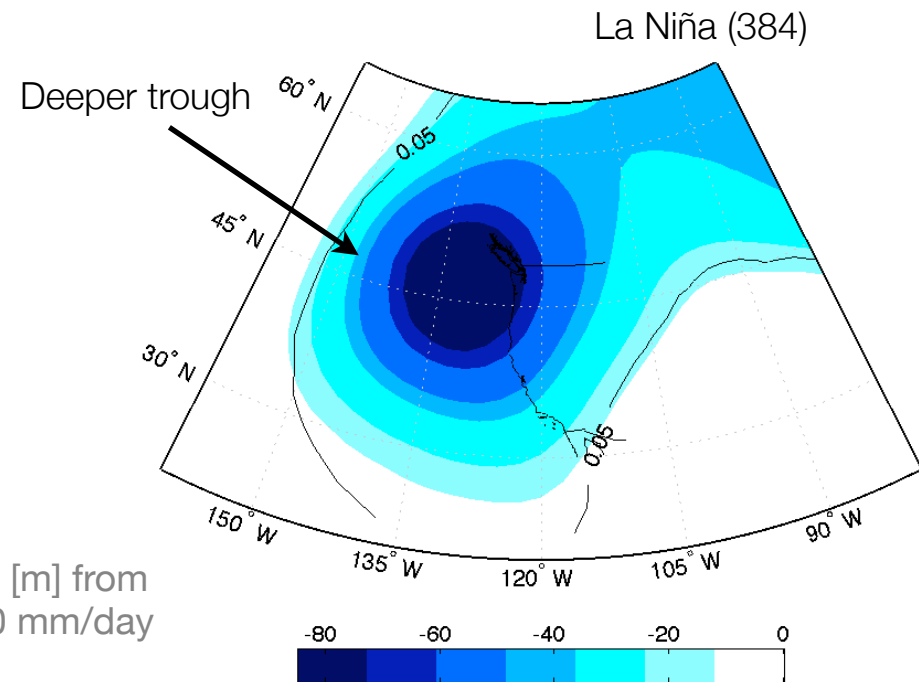
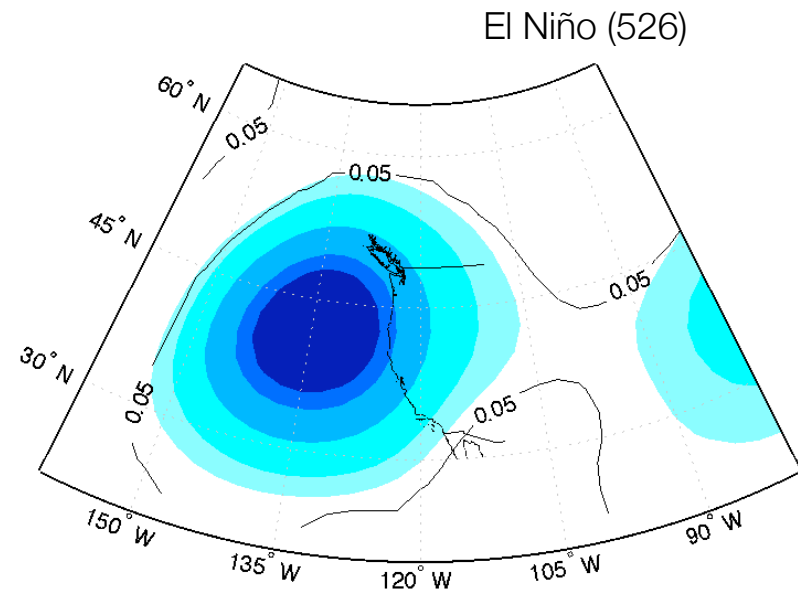


Composite of 500 hPa relative vorticity [s^{-1}] (shaded) and mean geopotential height [dam] (contours) for days of precipitation ≥ 20 mm/day south of 40°N [NCEP Reanalysis]



Geopotential height anomalies

- Anomalies from 30-day running mean
- During La Niña, low is displaced northwards but it is deeper and so it also extends farther south

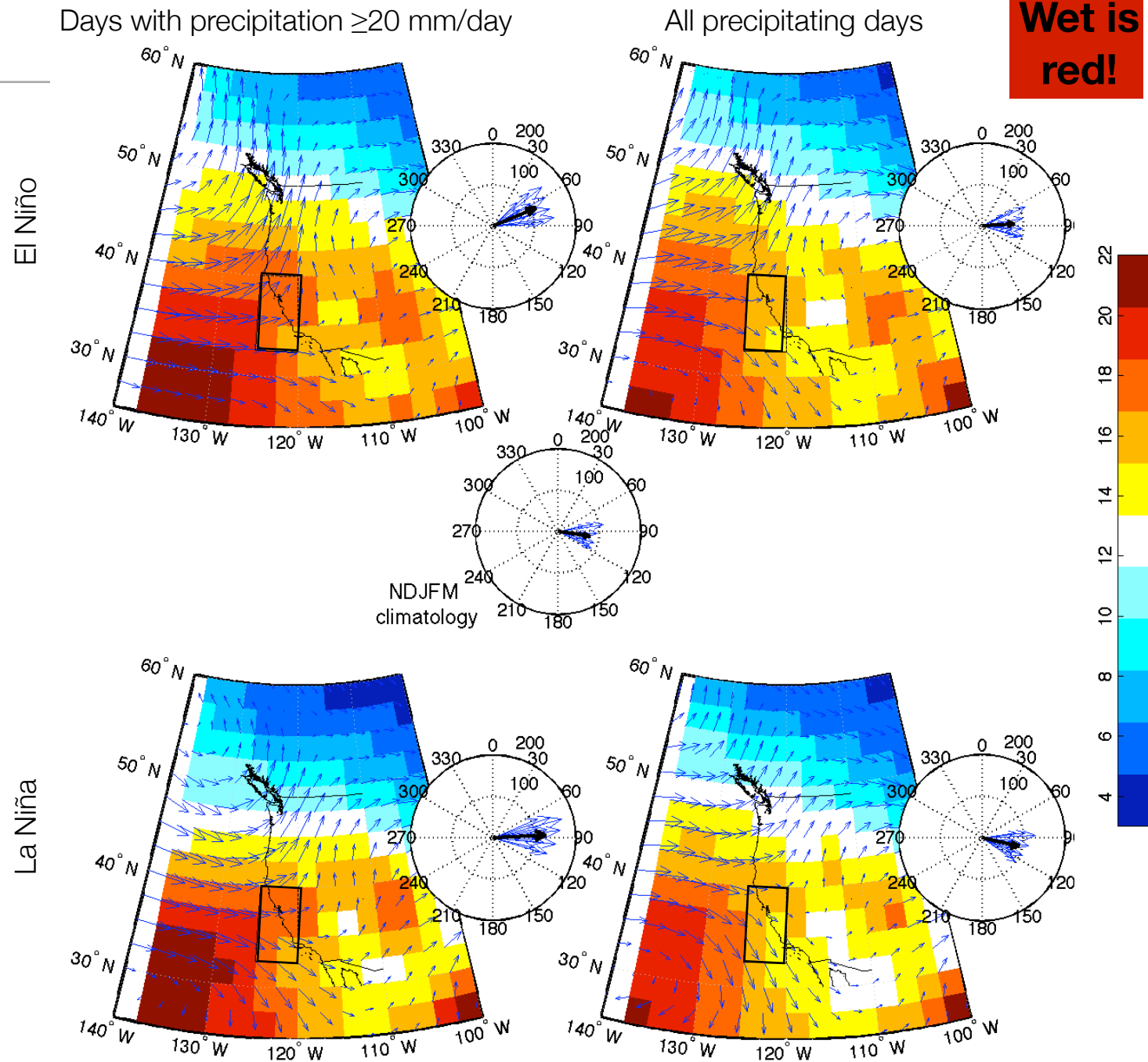


Composite of 500 hPa geopotential height anomalies [m] from the 30-day running mean for days of precipitation ≥ 20 mm/day south of 40°N [NCEP Reanalysis]

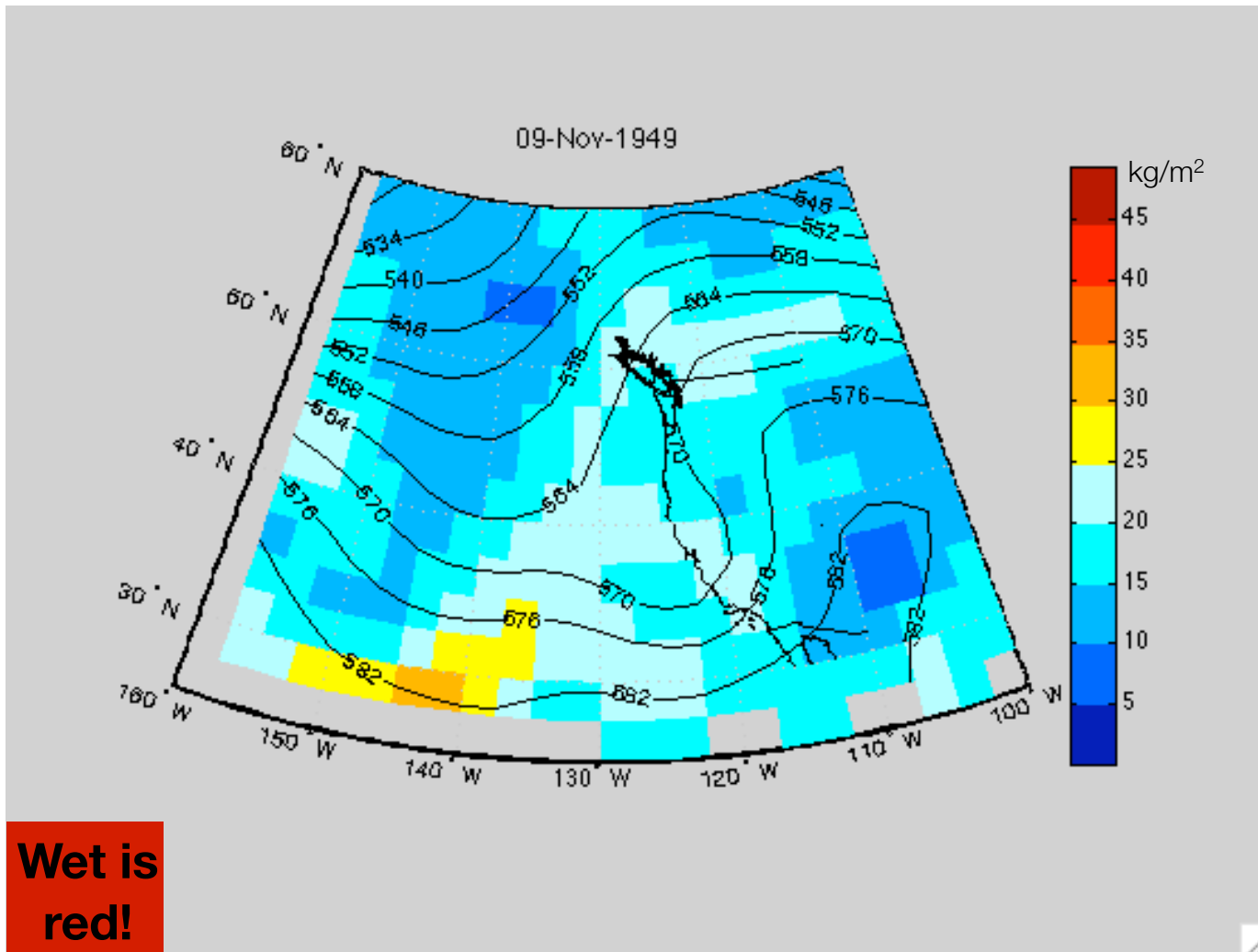
Moisture and moisture flux

Composite of column-integrated (300-1000 hPa) moisture [kg m^{-2}] (shaded) and 850 hPa winds (vectors) for precipitating days south of 40°N . Compass plots show column-integrated moisture flux [kg (ms)^{-1}] for the boxed region of the coastal southwest

- During intense-precipitation days, offshore moisture reservoir and onshore moisture flux are enhanced
- Slightly larger during La Niña
- Overall similarities suggest circulation differences matter more

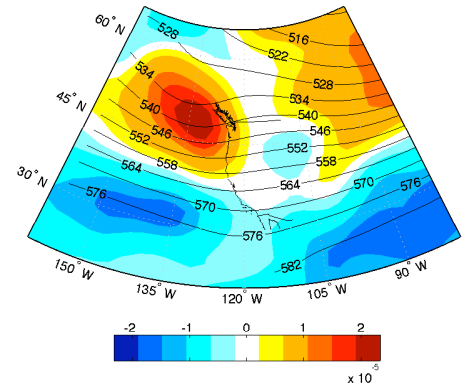


(Lots of) Variability amongst composite members

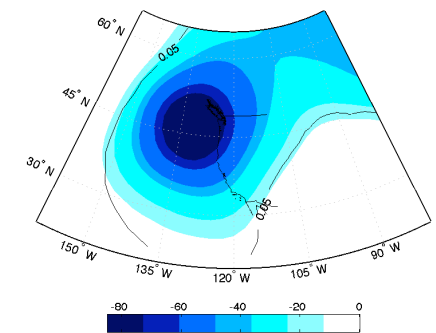


Column-integrated moisture [kg m^{-2}] (shaded) and mean 500 hPa geopotential height [dam] (contours) for La Niña days of precipitation ≥ 20 mm/day south of 40°N [NCEP Reanalysis]

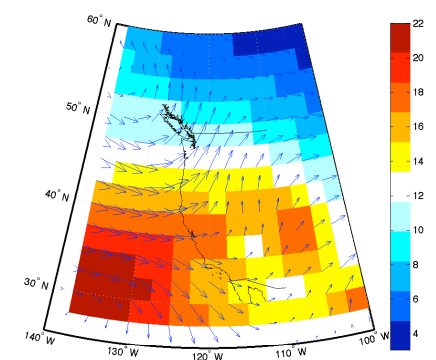
vorticity composite



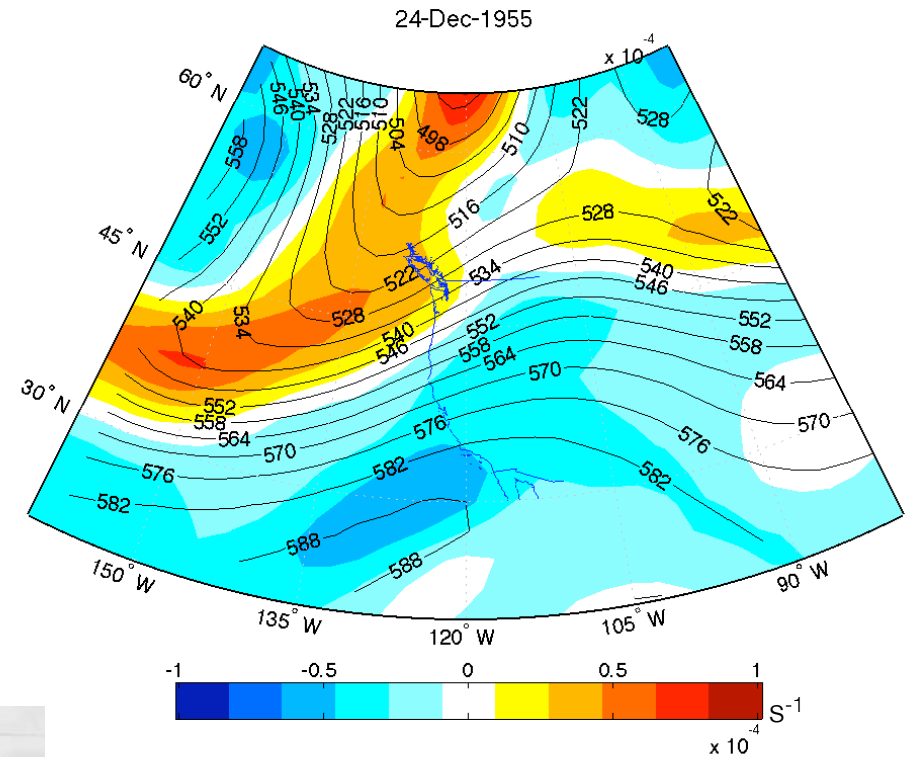
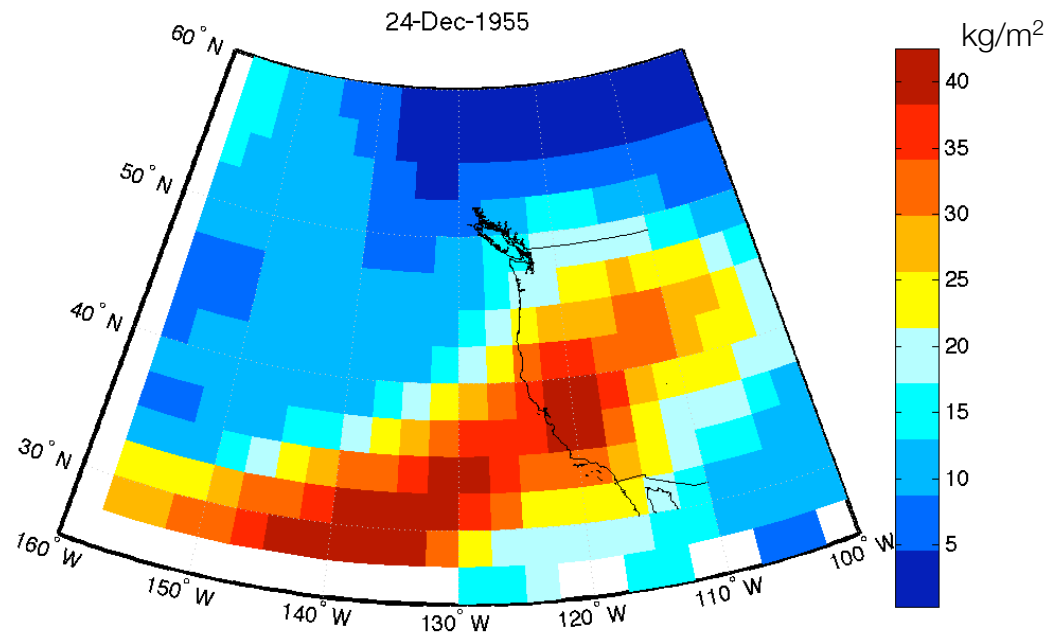
height composite



moisture composite



December 24, 1955



(still the) Wettest month on record!

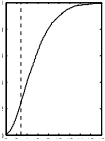
Synoptic interpretation

- ... of an unexpected but significant intense precipitation signal
- On average,

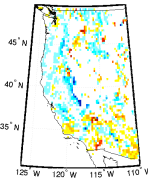
intensely-precipitating La Niña events south of 40°N = enhanced offshore moisture reservoir + trough digging unusually far south + trailing cold fronts

- Composite circulation patterns survive despite a large degree of variability
- Persistence (lagged composites vs. average decay time)

Summary and lessons



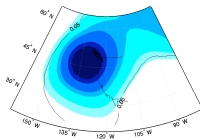
Redistribution of precipitation for different circulation regimes!



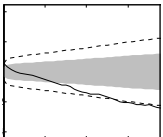
Spatial patterns of changes in mean, frequency, and intense precipitation demonstrate different responses to circulation variability; highlights important subtleties in regional climate predictability



Intense rain is more intense (but not more frequent!) during La Niña in the southwest



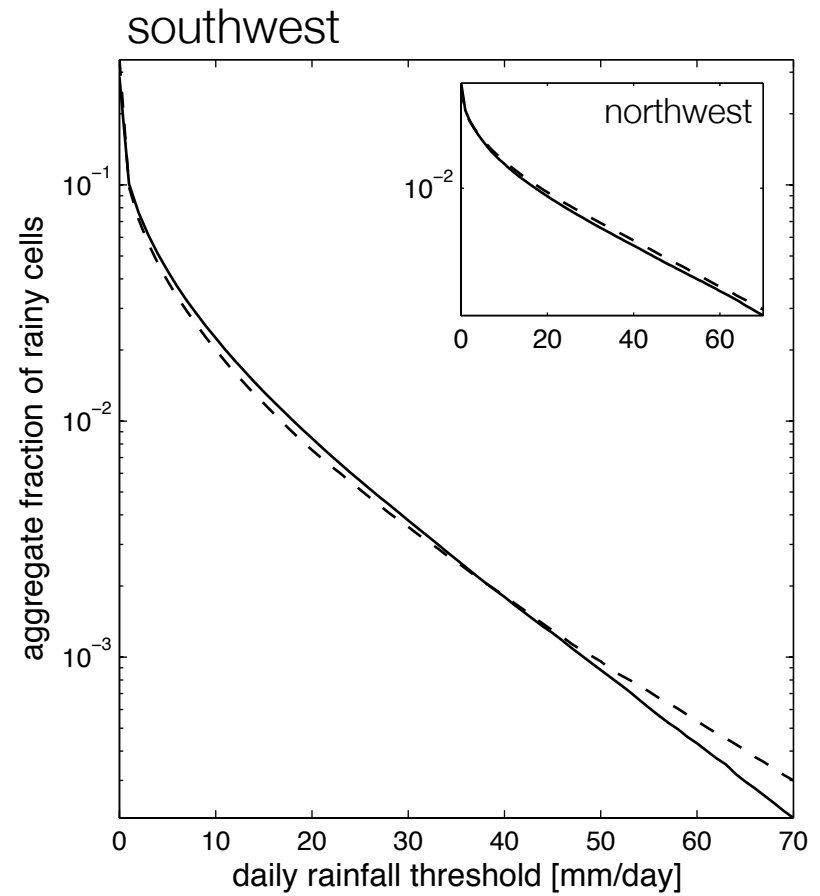
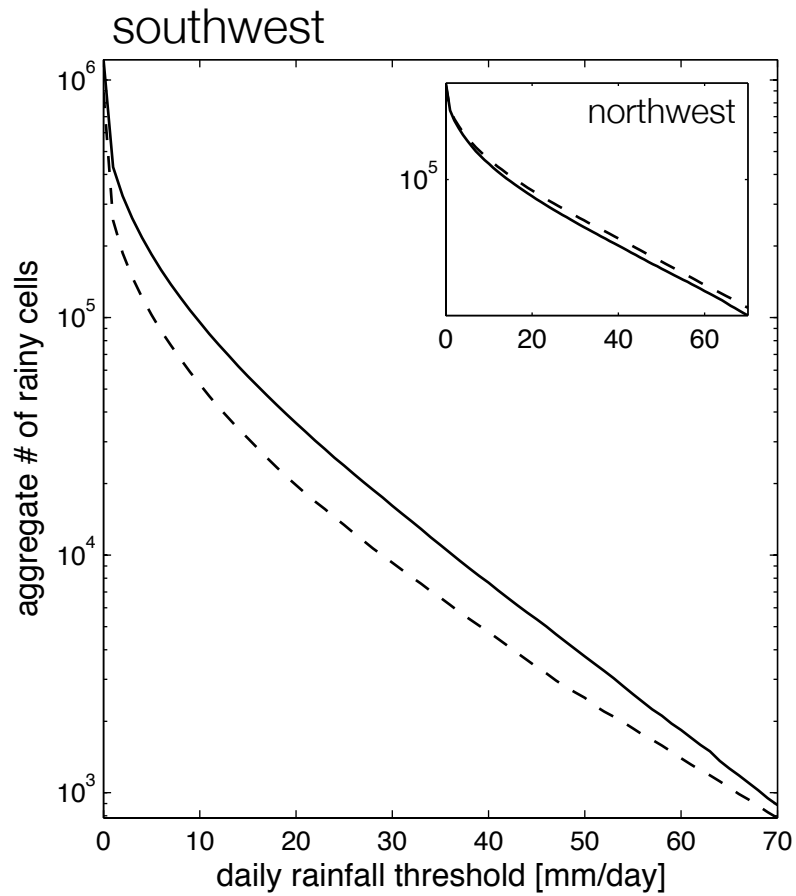
For a given La Niña storm, there may be a low centered far to the north, but if it's deep enough it can tap into subtropical moisture (if there's moisture) and deliver intense rain



The precipitation response to such events is significant in the regional mean for 50 years of data

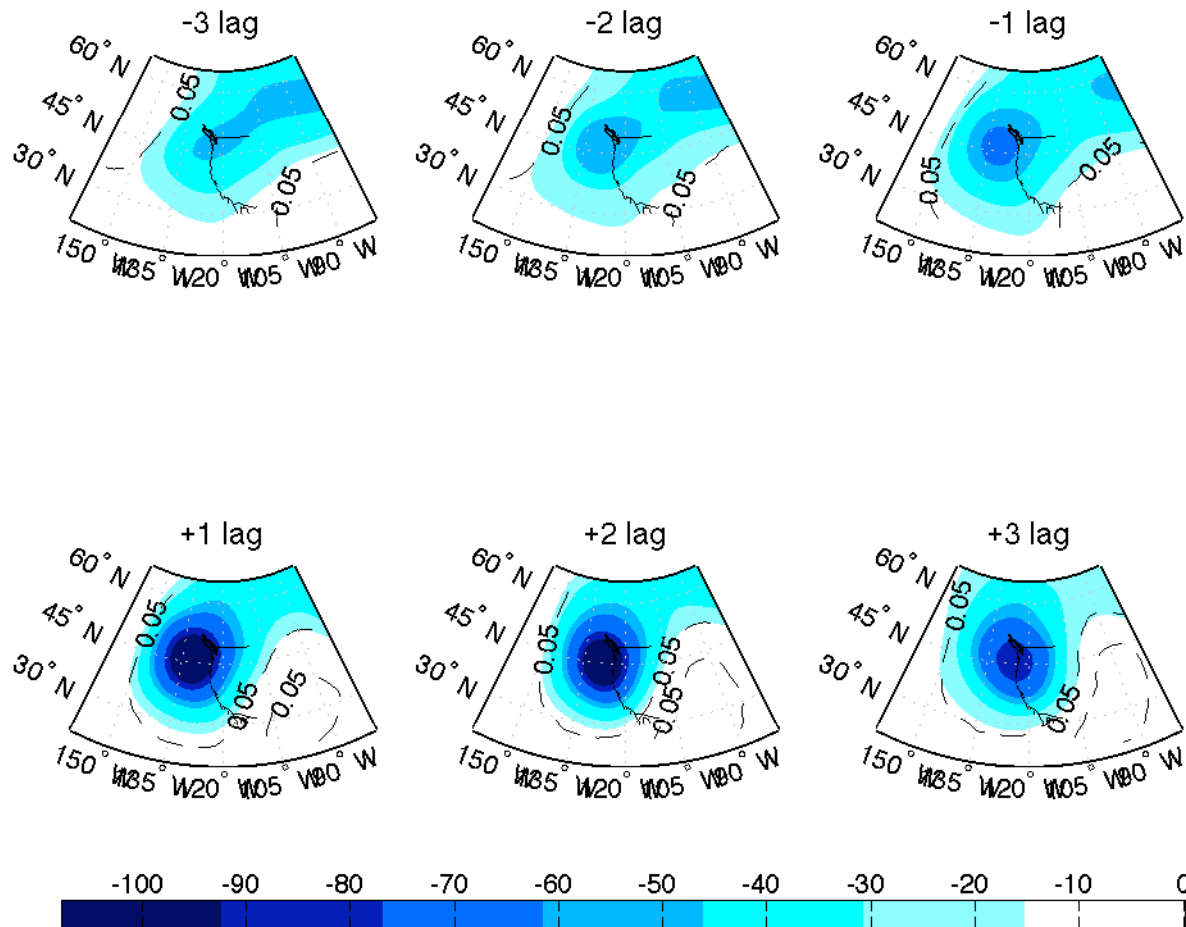
Thank you

Frequency



$$\bar{p}_{p_i \geq p^*} = \frac{\sum_{i > i^*}^{\infty} n_i p_i}{\sum_{i > i^*}^{\infty} n_i}$$

Persistence



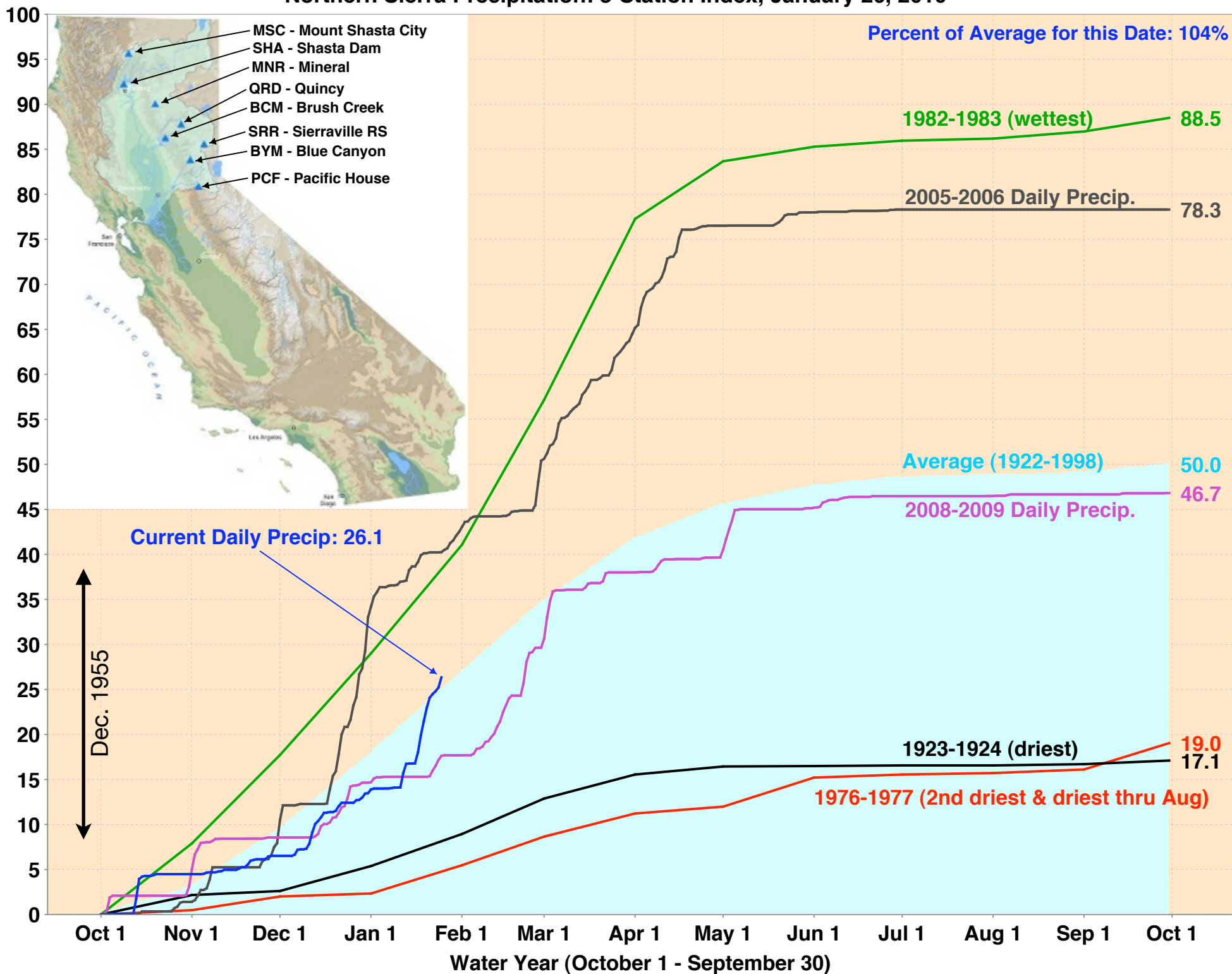
	southwest	northwest
Mean storm duration (≥ 20 mm/day)	1.4	1.5
Mean storm duration (≥ 0 mm/day)	5.5	9.3
Decay time of 500 mb anomalies for one winter (≥ 0 mm/day)	3.4	3.0

Data

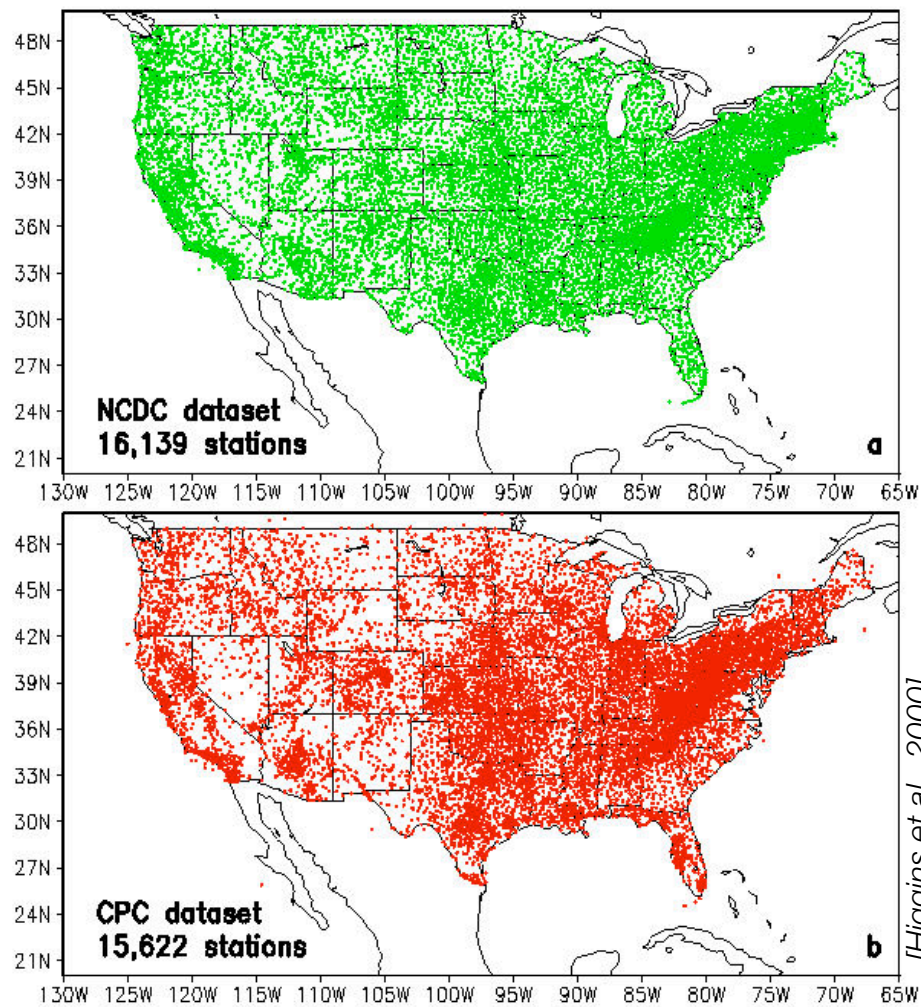
- CPC Unified Rain Gauge Database of gridded ($0.25^\circ \times 0.25^\circ$) daily data for 1948-1998 [Higgins et al. 2000]
- Wintertime (NDJFM)
- Best-available source of daily, high-resolution, multidecadal, and station-based precipitation for the region
- Strong ENSO events based on $>\pm 1K$ wintertime mean SST anomaly within Niño 3.4 region.

Northern Sierra Precipitation: 8-Station Index, January 26, 2010

Cumulative Daily/Monthly Precipitation (inches)

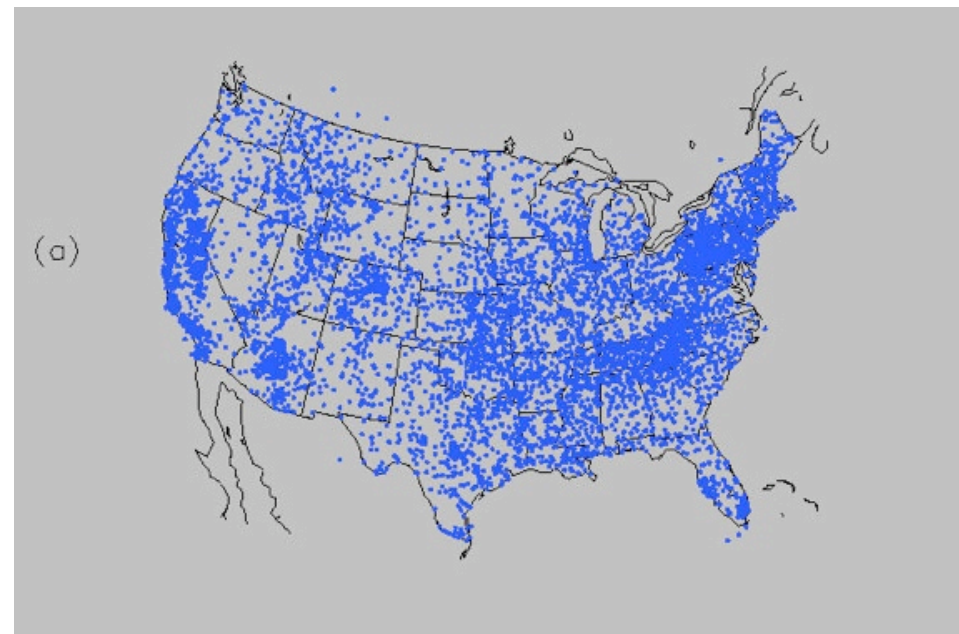


Total Water Year Precipitation



[Higgins et al., 2000]

Total number of stations that ever reported in (a) the NCDC Cooperative Dataset, (b) the CPC Cooperative Dataset. Typically, the number of daily reports is about 8000 and 7000 in the NCDC and CPC datasets.



[Higgins et al., 2000]

Typical station distribution for daily reporting stations in the United States from the CPC Cooperative Dataset. The dataset consists of reports gathered by the River Forecast Centers (~6000-7000 daily reports) and the Climate Anomaly Data Base (~400-500 daily reports). The analysis is gridded at a horizontal resolution of 0.25 degrees.

Station network for CPC Unified rain gauge database (NCDC + CPC)